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ABSTRACT

The purpose of this research was to develop a model of verbal information processing for use in subsequent analyses of the construct and predictive validity of the current Department of Defense military selection and classification battery, the Armed Services Vocational Aptitude Battery (ASVAB) 8/9/10. The theory and research methods of selected verbal information processing paradigms are reviewed. Work in factor analytic, information processing, chronometric analysis, componential analysis, and cognitive correlates psychology is discussed. The definition and measurement of cognitive processing operations, stores, and strategies involved in performance on verbal test items and test-like tasks is documented. Portions of the reviewed verbal processing paradigms are synthesized and a general model of text processing is presented. The verbal processing model serves as a conceptual framework for the subsequent identification and assessment of cognitive processing contributions to performance on the verbal subtests of ASVAB 8/9/10. (Author/PRN)

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Technical Report 648

Verbal Information Processing Paradigms: A Review of Theory and Methods

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Selection and Classification Technical Area
Manpower and Personnel Research Laboratory

U. S. Army
Research Institute for the Behavioral and Social Sciences

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processing is presented. The model was used as a conceptual framework for subsequent analyses of the construct and predictive validity of the verbal subtests of the Armed Services Vocational Aptitude Battery (ASVAB) 8/9/10.

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Verbal Information Processing Paradigms: A Review of Theory and Methods

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FOREWORD

The Selection and Classification Technical Area of the Army Research Institute for the Behavioral and Social Sciences (ARI) is concerned with developing effective procedures for the selection of applicants into military service and for the classification of accessions into Army occupational specialties. The purpose of this research was to develop a model of verbal information processing for use in subsequent analyses of the construct and predictive validity of the current Department of Defense military selection and classification battery, the Armed Services Vocational Aptitude Battery (ASVAB) 8/9/10.

EDGAR M. JOHNSON
Technical Director

VERBAL INFORMATION PROCESSING PARADIGMS:
A REVIEW OF THEORY AND METHODS

EXECUTIVE SUMMARY

Requirement:

To develop a model of verbal information processing for use in subsequent analyses of the construct and predictive validity of the Armed Services Vocational Aptitude Battery (ASVAB) 8/9/10.

Procedure:

The theory and methods of selected verbal information processing paradigms were reviewed. Work in factor analytic, information processing, chronometric analyses, componential analyses, and cognitive correlates psychology was discussed.

Findings:

The definition and measurement of cognitive processing operations, stores, and strategies involved in performance on verbal test items and test-like tasks were documented. Portions of reviewed verbal processing paradigms were synthesized and a general model of text processing was presented.

Utilization of Findings:

The verbal processing model served as a conceptual framework for the subsequent identification and assessment of cognitive processing contributions to performance on the verbal subtests of ASVAB 8/9/10. These results were also used in a series of analyses on the predictive validity of assessed constructs to successful performance in Army jobs.

VERBAL INFORMATION PROCESSING PARADIGMS:
A REVIEW OF THEORY AND METHODS

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VERBAL INFORMATION PROCESSING PARADIGMS:

A REVIEW OF THEORY AND METHODS

INTRODUCTION

Recent advances in cognitive psychology have resulted in methods for identifying the cognitive processing operations, memory stores, and strategies involved in performance on test items and test-like tasks. The cognitive processing operations, stores, and strategies that cognitive psychologists examine represent psychological constructs which may contribute to both item and subject differences in observed performance.

Current attempts at applying theories of human cognition to analyses of performance on cognitive tasks range from broad analyses of a number of tasks to specific and detailed models for performance on a single task type. The methods for analysis, similarly, range from intuitive analyses of performance to computer simulation of human protocols and mathematical modeling of response time and response accuracy. Investigations of the algorithms and heuristics people use in processing information have focused on very simple cognitive tasks such as, deciding whether or not two visually presented letters are the same or different, to complex cognitive activities like reading text and solving algebra word problems. The ability components employed by these models, likewise, span a wide range.

Recent attempts at applying theories of human cognition to analyses of performance differences on test items suggest general dimensions along which differences are manifested. Investigations of cognitive ability components relevant to performance on test items and test-like tasks have focused on verbal and imaginal encoding; retrieval; code access; categorization; executive control; rule induction; inference; semantic, procedural and strategic knowledge; memory span; spatial visualization; etc. Various test-like tasks have been examined; these include tasks involving verbal analogy processing (Sternberg, 1977a, 1977b, 1980; Gentile et al., 1977; Pellegrino & Glaser, 1979, 1980; Barnes & Whitely, in press; Whitely & Barnes, 1979; Whitely & Schneider, 1980), geometric analogy processing (Mullholland, Pellegrino, & Glaser, 1980), syllogistic reasoning and transitive inference (Falmagne, 1975; Sternberg, 1979, 1980; Sternberg et al., 1980; Sternberg & Weil, 1980), spatial rotation and visual comparison (Egan, 1979; Cooper, 1980), block design problems (Royer, 1977), matrix pattern abstraction (Hunt, 1974), and comprehension of text (Frederiksen, 1978, 1980).

A brief summary of the theory and methods of cognitive processing paradigms relevant to the analysis of performance on verbal tasks follows. Processing operations, strategies and structures with a history of empirical and theoretical support are presented. Relevant measurement methodologies and analytic techniques are discussed.

THE FACTOR ANALYTIC APPROACH TO THE EXAMINATION OF VERBAL PERFORMANCE

The structure of cognitive ability as it relates to performance on tests and test-like tasks has traditionally been examined using factor analytic and related methodologies. The research pioneers of the factor analytic movement--Spearman, Thomson, Thurstone--have paved the way for the use of solid, empirically based analyses in aptitude test construction and validation. Factorial methods have been developed, according to Thurstone (1947, p. 55), for the purpose of "...identifying the principal dimensions or categories of mentality". Guilford (1967, p. 41) describes the goal of factor analysis as the identification of "...an underlying latent variable along which individuals differ".

Factor analytic methods can be employed at the stages of both hypothesis formulation and hypothesis testing. In the first instance, factor analysis serves as a useful exploratory technique. It allows analysts to derive a "... crude first map of a new domain" (Thurstone, 1947, p. 56). Exploratory factor analytic examinations of items, subtests or intact tests then allow one to proceed beyond initial stages to more direct forms of psychological experimentation in the laboratory. In the second instance, factor analysis can be employed as a "... method of comparing, confirming, or refuting alternative hypotheses initially suggested by nonstatistical arguments or evidence" (Burt, 1970, p. 17).

Factor analysis begins with a matrix of intercorrelations among items, subtests, or tests and distributes variance within variables and between factors in such a way that a set of underlying hypothetical performance constructs are suggested. The output from the factor analysis is a factor structure or factor pattern matrix of correlation coefficients between each variable, item or test, and each underlying factor. The factor matrix for a given factor analysis is typically rotated to some mathematically permissable coordinate reference system to facilitate interpretation.

The factor analytic definition and measurement of verbal ability is well documented. Verbal comprehension, defined as "...the ability to understand the English language," is referenced in at least 125 published studies (Ekstrom, French & Harman, 1976, p. 163). Tests of vocabulary, similarities, opposites, verbal analogies, proverbs, quotations, grammar, spelling, and paragraph and reading comprehension have loaded highly on the verbal factor in a number of studies. Verbal factors have been variously titled word knowledge, word fluency, verbal reasoning, cognition of semantic units, and cognition of semantic relations or systems. The basic distinctions between factor types may be summarized as follows: word fluency is typically characterized by tests dealing with single and isolated words; facility with grapheme or phoneme relations rather than semantic knowledge is tapped. The word knowledge factor taps semantic knowledge; it seems to reflect experience with and knowledge of the English language. The verbal reasoning factor may be seen as reasoning in reading or the ability to see relationships among ideas, to draw inferences from a paragraph or derive the principal thought or idea from a passage.

For the purposes of studying cognitive ability component differences relevant to performance on standardized tasks, factor analytic methods can play a promising role in theory-oriented research. Factor analyses of item or subtest data can be used to confirm or refute theory-oriented characterizations or processing requirements for items and tests. Alternatively, theory-oriented characterizations of cognitive processing operations, stores, and strategies underlying test item performance can be detailed and "...the role of various processes in a total matrix of cognitive operations," can be identified (Carroll, 1976, p. 41). An example of the application of factor analytic methods to the examination of human information processing is seen in the work of John Carroll; a description of his work is included below.

THE RATIONAL ANALYSIS APPROACH TO THE EXAMINATION OF VERBAL PERFORMANCE

Using Hunt's Distributive Memory Model (discussed more fully in a later section), Carroll has attempted a rational and empirical analysis of the necessary and sufficient cognitive processing operations, stores, and strategies underlying performance on the 74 psychometric tests of the French, Ekstrom and Price (1973) Kit of Reference Tests for Cognitive Factors. Research suggests that the French Kit contains good marker tests for 24 different cognitive ability factors.

The memory model employed by Carroll depicts the processing of language messages in stages. The first stage is a decoding stage, in which arbitrary physical patterns are recognized as representations of language concepts. The second stage is an active memory stage, in which the recognized lexical items are rearranged in memory until they form a coherent linguistic structure. The third stage is a sentence producing stage, in which the semantic meaning of the linguistic structure is extracted and incorporated into our knowledge of the current situation. In the fourth stage, the current situation itself is analyzed with respect to information held in long term memory, and if appropriate, a response is chosen and emitted. A control or executive system directs the flow of information in the processing system and has access to the various levels of memory storage (Hunt, 1971, 1973, 1980).

Carroll has developed a uniform system for classifying the characteristics of the tasks represented by the items of each test in the French Kit. The classificatory scheme addresses the types of stimuli presented, the kinds of overt responses that are required to demonstrate performance, the sequencing of subtasks within the tasks, the cognitive processing operations, stores, and strategies that Carroll, conceiving himself as a subject, would employ in performing the test tasks, and ~~the~~ probable ranges of relevant temporal parameters. The scheme considers the term and contents of memory that would probably be addressed in storage, search, and retrieval operations.

The cognitive processing operations and strategies outlined by the system (Carroll, 1976) are processes that are explicitly specified or implied in task instructions and that are necessary to successful completion of the task. These operations and strategies are of three types: attentional, memorial, and executive. The latter two are further subdivided as follows--there are three kinds of memorial operations--storing, searching, retrieving. Executive strategies are exemplified by such things as simple judgements of stimulus attributes such as to reveal identity, similarity, or comparison between two stimuli; manipulations of memorial contents, such as 'mentally rotating' a visiospatial configuration; and information transformations that produce new elements from combinations, reductions, etc. of old elements. In all, twenty different operations and strategies are outlined; they are:

1. Identify, recognize, interpret stimulus
2. Educe identities or similarities between two or more stimuli
3. Retrieve name, description, or instance from memory
4. Store item in memory
5. Retrieve associations, or general information, from memory
6. Retrieve or construct hypotheses
7. Examine different portions of memory
8. Perform serial operations with data from memory
9. Record intermediate result
10. Conduct visual inspection of stimulus
11. Reinterpret possible ambiguous item
12. Image, imagine or form abstract representation of stimulus
13. Mentally rotate spatial configuration
14. Comprehend and analyze language stimulus
15. Judge stimulus with respect to a specified characteristic
16. Ignore irrelevant stimuli
17. Use a special mnemonic aid
18. Rehearse associations
19. Develop a special search strategy
20. Chunk or group stimuli or data from memory (Carroll, 1976, p. 39).

Carroll has used his classification scheme as a basis for specifying the potential sources of individual differences underlying each of the 24 French Kit cognitive ability factors. He postulates that individual differences might arise through: (1) differences in the composition and ordering of processing operations and execution rules incorporated in the system; (2) differences in the temporal parameters associated with those execution rules; (3) differences in the processing capacity of the executive and its associated memory stores; and (4) differences in the contents of long term or permanent memory stores.

Carroll has found that nearly all pairs of tests from the same factor have one or more classification codes in common and that the patterns of the codes are generally distinct from factor to factor. The cognitive processing operations, stores, and strategies identified as being characteristic of the 24 factors and the tests that represent them are quite diverse with respect to type of operation and memory store involved, temporal parameters and other details. A description of the factors defined by verbal tasks and the cognitive processing operations, stores, and strategies characterizing these factors includes:

1. Factor FW (Word Fluency) is the facility to produce words that fit one or more structural, phonetic or orthographic restrictions unrelated to the meaning of words. The cognitive processing operation involved in word fluency is a search of a "lexiographemic" portion of long term memory for instances fitting the orthographic requirements. Strategies may include the use of an alphabetic mnemonic to search the memory systematically. French Kit tests loading on this factor are: (a) Word Endings tests, where the task is to write as many words as possible ending with certain given letters, (b) Word Beginnings test, where the task is to write as many words as possible beginning with given certain letters and (c) Word Beginnings and Endings test, where the task is to write as many words as possible beginning with one given letter and ending with another.

2. Factor FA (Associational Fluency) is the ability to produce rapidly words which share a given area of meaning or some other commmon semantic property. Associational fluency entails a search of a major portion of a long term lexicosemantic store, with special attention to semantic or associational aspects. Strategies may involve searching long term memory for different meanings of the stimulus word. Tests loading on this factor are: (a) Controlled Associations tests, where the task is to write as many synonymns as possible for each of four words, (b) Opposites test, where the subject is asked to write up to six antonyms for each of four words, and (c) Figures of Speech, where the subject is asked to provide up to three words or phrases to complete each of five figures of speech.

3. Factor FE (Fluency of Expression) is the ability to think rapidly of word groups or phrases. Like associational fluency, expressional fluency involves a search of lexiosemantic memory but with special attention to grammatical features of lexical items and different syntactical patterns of phrases and sentences. Cognitive processing strategies may involve the use of grammatical mnenomics such as considering grammatical classification in the search for words. Tests loading on this factor are: (a) Making Sentences, where the subject is asked to make sentences of a specified length when the initial letter of some of the words is provided, (b) Arranging Words, where the subject is asked to write up to twenty different sentences using the same four words, and (c) Rewriting, where the subject is asked to rewrite each of three sentences in two different ways.

4. Factor V (Verbal Comprehension) is the ability to understand English words. This factor is almost exclusively dependent on the contents of lexicosemantic long term memory store, i.e., upon the probability that the subject can retrieve the correct meaning of a word. Tests loading on this factor are: (a) Vocabulary I, a four choice synonym test, (b) Vocabulary II, a five choice synonym test, (c) Extended Range Vocabulary test, a five choice synonym test having items ranging from very easy to very difficult, (d) Advanced Vocabulary I, a five choice synonym test consisting mainly of difficult items, and (e) Advanced Vocabulary II, a four choice vocabulary test consisting mainly of difficult items. Carroll states that a more diversified set of tests of this factor would probably call on other aspects of the lexiosemantic store, particularly on the grammatical feature portions.

THE INFORMATION PROCESSING APPROACH TO THE EXAMINATION OF VERBAL PERFORMANCE

Although each of the paradigms discussed here may be thought of as information processing paradigms, a more general discussion of verbal information processing may be informative. The information processing viewpoint holds that performance on cognitive tasks may be described by the operation of integrated programs for the processing of information available from sensory channels and memory stores. The paradigm poses that the presentation of stimuli initiates a sequence of processing stages. Each stage operates on the information available to it. The operations transform the information in some manner; furthermore, these operations take a measurable amount of time. The output of each processing stage is in the form of transformed information, and this new information is the input to the succeeding stage.

The operations, stores, and strategies of the human information processing system are usually described as analogues to computer system structures. The cognitive ability components are used to formulate information processing models of tasks. The major concern of information processing research is to identify cognitive processing operations, stores, and strategies and to determine how they operate.

Most general models of the human information processing system include a short term sensory storage or buffer component, a memory component consisting of two or three subsystems distinguished by relative time duration of information storage--short term, intermediate term or working memory and long term storage; a response selection or generation component; and a central or executive processor. There is much less unanimity in the literature with respect to the cognitive processing operations and strategies.

Rose (1980) describes a number of cognitive processing operations which have a history of empirical and theoretical support. His compendium includes:

1. Encoding, the operation by which information is input into the processing system, including the initial set of operations that converts the physical stimulus to a form that is appropriate for the task. Different task demands may require different levels of analysis of the stimulus. Posner (1969) has called this dimension "abstraction," the operation by which diffent types of information about the stimulus are extracted.

2. Constructing, the operation by which new information structures are generated from information already in the processing system. This is what Neisser (1967) and others have called "synthesis."

3. Transforming, the operation by which a given information structure is converted into an equivalent structure necessary for task performance. In contrast to constructing, transformations do not involve any new information abstraction; rather, this operation requires the application of some stored rules to the information structures already present.

4. Storing, the operation by which new information is incorporated into existing information structures while its entire content is retained.

5. Retrieving, the operation by which previously stored information is made available to the processing system.

6. Searching, the operation by which an information structure is examined for the presence or absence of one or more properties. The information structure examined may be one already in the processing system or one external to it.

7. Comparing, the operation by which two information structures, either internal or external to the processing system, are judged to be the same or different. The structures need not both be physical entities, for example, a physical entity may be compared to a stored representation or description in order to determine identity.

8. Responding, the operation by which the appropriate motor action is selected and executed.

Newell and Simon (1972) and Simon (1976) have shown that systems of cognitive ability components can be depicted by computer simulations of complex problem solving activities, such as the solving of chess or symbolic logic problems. They have determined the cognitive processing operations, stores, and strategies necessary for a computer program to extrapolate sequential material such as number or letter sequences, to translate and solve algebra word problems, the Tower of Hanoi puzzle, perception in chess, to understand task instructions, and to spell English words. A running program serves as a built-in empirical test via computer modeling.

THE COGNITIVE CORRELATES APPROACH TO THE EXAMINATION OF VERBAL PERFORMANCE

What Pellegrino and Glaser (1979) have referred to as the Cognitive Correlates approach to individual differences can be traced back to the work of Hunt, Frost and Lunneborg (1973). This line of research has been continued by Hunt and his associates throughout the decade (Hunt, 1974; Hunt, Lunneborg & Lewis, 1975; Hunt & Lansman, 1975; Hunt, 1976, 1978). The basic premise behind their work is that examinee performance on relatively simple laboratory tasks can be used to identify cognitive ability components underlying performance on complex cognitive tasks Hunt and his colleagues examine tasks that are theoretically related to performance on verbal information processing problems in order to determine how behavior on these tasks is related to performance on verbal aptitude tests. The goal of this approach is to specify the cognitive ability components that are differentially related to high and low levels of verbal competence.

Hunt and his colleagues posit that there are two types of cognitive ability components underlying verbal performance. The first set of components is based on semantic knowledge, on the ability to deal with words and the concepts they represent. The second set of components is based on strategic knowledge, on the exercise of information-free, mechanistic operations. These operations dictate the transformation of both the internal and external physical representation of a symbol; these strategic knowledge operations do not depend on information associated with the symbol. They are the means by which information structures are transformed into equivalent structures necessary for task performance. Hunt and his colleagues propose that effectiveness in verbal information processing depends on the relation of the stimulus information to the information structures stored in semantic memory, on the way the information is organized, and on the manipulative efficiency of the mechanistic processes.

As is typical of most modern theories of cognition, the model employed by Hunt and his colleagues draws a distinction between two types of memory. The first is a relatively small active memory and the second is a theoretically infinite long-term memory. Long term memory may be thought of as a collection of basic memory units or engrams in conjunction with the associations that define them. The engrams, collectively, represent the semantic knowledge information structures and the mechanistic, information-free structures. Verbal information processing takes place when active memory images, aroused partly by the recognition of current input and partly by the recognition of the previous state of active memory, are supplemented by semantic knowledge information structures and transformed by processes controlled both by sensory input and by the arousal of strategic knowledge-based structure rules stored in long-term memory. This model is Hunt's Distributive Memory Model discussed above.

With this model as a frame of reference, Hunt and his colleagues ask questions about differences between examinees representing a wide range of verbal competence. Tests of verbal ability, composites that test knowledge about syntax, spelling, vocabulary, and the ability to comprehend brief statements, are administered to subjects and the data are used to identify ability subgroups. Subgroup performance is then compared on laboratory tasks, which have cognitive ability component characteristics defined by prior investigations.

Hunt and his colleagues have conducted laboratory experiments to examine individual cognitive ability component differences in (1) lexical recognition, arousal speed; (2) speed of information manipulation in short term memory; (3) storage differences in short and intermediate term memory; (4) speed of information transmission from place to place in the total system; (5) programming which shifts the burden of information processing from one component of the memory system to another; and (6) attention allocation (Hunt, 1976, 1980). Hunt and his colleagues have observed individual differences in these processes within the population represented by university students and within a population of somewhat lower than average ability. These differences appear to account for a moderate portion of individual variation in verbal competence.

In their examination of the decoding operation, for example, they have found evidence for a clear association between verbal competence and the simple act of identifying highly overlearned symbols. Their research in this area has relied primarily on the letter identification task developed by Posner and Mitchell (1967). In the Posner task, two letters are presented simultaneously on a visual display screen and the subject's task is to indicate whether the letters are the same or different. Under physical identity (PI) instructions, letter pairs are to be identified as 'same' only if the letters are exact duplicates of each other, as in the pair (AA). Under name identity (NI) instructions, letter pairs are to be called 'same' if they are different visual codes for the same letter, as in the pair (Aa). The difference between reaction time to classify an item as same under name identity instructions and the time to classify an item as same under physical identity instructions is assumed to reflect the extra processing operations required to carry the analysis to the same level. Hunt cites moderate negative correlations for the difference measure and verbal aptitude. Low verbal subjects are seen to have high difference scores and high verbal subjects are seen to have low difference indices.

Hunt, Lunneborg and Lewis (1975) have examined the active memory capacities of high verbal and low verbal college students using a version of the Brown-Peterson short term memory paradigm. In this procedure the subject is shown four letters, asked to repeat a string of digits presented visually, and finally to recall the four letters. A positive correlation is observed between examinee behavior on the task and verbal aptitude test performance. High verbal students are seen to code items more rapidly than low verbal students and high verbals have a lower relative error frequency. Hunt and his colleagues postulate that the observed differences are associated with language competence. Greater short term memory capacity, they say, may indicate an increase in the strategies that a high verbal individual can use in verbal problem solving.

Hunt (1978) has also examined the relationship between sentence verification reaction time and measures of verbal aptitude. The task, developed by Clark and Chase, is designed to assess how subjects compare information from various sources in order to verify sentences. Subjects are presented with a display containing a sentence and a picture. The subject is asked to determine whether the sentence is an accurate or inaccurate representation of the picture. The display sentences are of the form:

'Star (plus) is (is not) above (below) plus (star).'

Sentences can be either positively or negatively worded. They can be either true or false representations of the displays:

+ *
* +

There are four possible sentence combinations: A true affirmative description, a true negative description, a false affirmative description, and a false negative description. The dependent variable is the latency of the subject's judgements.

It is hypothesized that subjects will first encode the sentence and picture, then perform transformations based on the modifiers in the presented sentences, e.g., transform 'below' to 'not above,' and finally compare the sentence and picture. The differences in processing time for the four conditions are assumed to reflect the number of transformations that must be executed to process the sentence as well as the complexity of the comparison of the verbal and pictorial representations. Findings are seen to be consistent with this hypothesis. A negative correlation is evidenced for response latency and verbal competence.

THE COMPONENTIAL ANALYSIS APPROACH TO THE EXAMINATION OF VERBAL PERFORMANCE

Sternberg says that his (1977a, 1977b, 1979) componential theory of cognitive performance is directed at the analysis of performance differences in the elementary operations involved in task performance, in the strategies of task performance into which processes combine, and in the representations of information upon which the operations and strategies act. A component is defined as an elementary information process that operates upon internal representations of objects or symbols (Newell & Simon, 1972). A component may translate sensory input into a conceptual representation, transform one conceptual representation into another, or translate a conceptual representation into motor input. Components are classified by level of generality and function.

Sternberg describes general components, for example, encoding and response components, as prerequisite to successful performance of all tasks of a global task type, e.g., reasoning tasks. Class componenents, such as inference, mapping relations, or applying relations, are components common to a particular class of tasks, for example, inductive reasoning tasks. Specific components are required for performance of single tasks within a task universe.

Components perform five different kinds of functions. Metacomponents are higher-order control processes used for planning how a problem should be solved, for making decisions regarding alternate courses of action during problem solving, and for monitoring solution processes. These are analogous to the executive or control subsystems discussed above. Performance components are processes that are used in the execution of a problem solving strategy. Acquisition components are processes used in learning new information. Retention components are processes used in retrieving previously stored knowledge. Transfer components are used in carrying knowledge over from one task or task context to another.

Componential analysis defines information processing models of performance that specify: (1) the nature and order of component process execution, and (2) the mode of component execution, that is, whether components are executed serially or in parallel, as self terminating or exhaustive processes, holistically or particularistically. Cognitive tasks may be decomposed using the methods of partial tasks, stem splitting, systematically varied booklets, and the method of complete tasks. The method of stem splitting is discussed for illustrative purposes.

The method of stem splitting involves items requiring the same number and type of information processing components, but with different numbers of executions of the various components. The method of stem splitting applied to a verbal analogy task, for example, might take the following form:

1. red : blood :: white : (a) color
   (b) snow

2. red : blood :: (a) white : snow
   (b) brown : color

3. red : (a) blood :: white : snow
   (b) brick :: brown : color

The first item involves the encoding of five terms--red, blood, white, color, and snow; the inference of one relation, the color/substance relation; the mapping of one relation, the color/substance relation onto white and its alternatives; the application of two relations, the color/substance relation onto color and snow; and one response, b. The second item requires the encoding of six terms--red, blood, white, snow, brown, and color; the inference of one relation, again, the color/substance relation; the mapping of two relations, the color/substance relations onto white and brown; the application of two relations, the color/substance relations onto white/snow and brown/color; and one response, a. The third item requires encoding of seven terms, inference of two relations, mapping of two relations, application of two relations, and one response. The primary dependent variable for the analogy task might be solution latency or response choice. Controls are introduced for requirement differences in the encoding process. The cognitive processing contributions of the inference, mapping, and application of relation components may then be individually examined. Experimental results suggest the psychological reality of each of the three components in verbal analogy processing. Solution latency increases with additional executions of the various components; response accuracy also decreases for the more complex items.

Sternberg has examined such task types as linear categorical and conditional syllogisms, and verbal and schematic-picture analogies. Componential models accounting for as much as 96% of the variance in solution latency and response choice data have been constructed.

THE COGNITIVE PROCESS OUTCOME MODELING APPROACH TO THE EXAMINATION OF VERBAL PERFORMANCE

Also working in the area of componential analysis is Whitely (1980, 1981; Barnes & Whitely, in press; Whitely & Barnes, 1979; Whitely & Schneider, 1980, 1981) and her colleagues at the University of Kansas. These researchers have also examined cognitive processing operations, stores, and strategies in terms of performance on test items and test-like tasks. These researchers charge test developers to begin the test construction process by elaborating theories of item tasks. The theories can then be used as item specifications in test development. Cognitive process outcome models can be used to factor item and examinee response variance in accordance with componential theories of task performance. Multicomponent latent trait and linear logistic latent models can be employed to relate cognitive ability component performance to ability test outcomes.

These latent trait models assume that aptitude test items can be decomposed into subtasks that reflect an exhaustive set of cognitive processing components. Cognitive ability components are defined by item subtasks and/or stimulus information measures, that is, by records of the cognitive processing operations, stores, and strategies purportedly involved in performance on a test item. The models specify both a mathematical model of item performance and a latent trait model for cognitive ability components. The latent trait models express the probability of success on each subtask as a logistic function of item difficulty and person ability on the underlying cognitive ability component. The mathematical model expresses the probability of success on the total item as the joint probability of passing the subtasks for each cognitive ability component. Models have been developed to estimate joint, conditional and marginal maximum likelihoods for the multicomponent and linear logistic latent trait models.

The linear logistic latent trait model will be discussed for the purposes of illustration. This technique models item difficulty from stimulus information. Maximum likelihood estimates of person ability and cognitive ability component contributions to item difficulty are generated. The linear logistic latent trait model is similar to the Rasch model in that only item difficulty is examined; no discrimination or guessing parameters are postulated. The following equation is the Rasch model for the probability that person *j* passes item *i*:

$$1. \quad P_{(x_{ij}=1)} = \frac{\exp(\xi_{ij} - \sigma_i)}{1 + \exp(\xi_j - \sigma_i)}$$

where ξ_j =the ability level for person *j*, and

σ_i =the difficulty for item *i*.

The linear logistic latent trait model factors item difficulty into a subset of *m* stimulus complexity components according to the following linear model.

$$2. \quad \sigma'_i = \sum_m (f_{im} \eta_m) + \alpha$$

where f_{im} =the number of executions of component m that are involved in solving item i,

η_m =the difficulty of processing component m, and

α =a normalization constant.

The complete linear logistic model, then, is given:

$$3. \quad P_{(x_{ij}=1)} = \frac{\exp(\xi_{ij} - (\sum_m f_{im} \eta_m + \alpha))}{1 + \exp(\xi_{ij} - (\sum_m f_{im} \eta_m + \alpha))}$$

Maximum likelihood estimates are computed for the parameters; an estimate for the difficulty of each cognitive ability component is obtained along with standard errors and error correlations. Examinee item and component likelihoods are computed.

Cognitive process outcome analyses involve: (1) testing alternative component models of response accuracy, (2) decomposing item difficulty into cognitive ability component contributions, and (3) assessing the cognitive processing operation, store, and strategy person parameters as individual difference measures. Whitely and her colleagues have examined verbal and geometrical analogy tasks.

Performance on verbal analogy and verbal classification test items has been modeled by Whitely and her collegaues in terms of such cognitive processing operations as image construction and response evaluation. The image construction operation involves defining the attributes of the ideal solution of an item; response evaluation involves selecting the response alternative that best fulfills a given set of ideal solution attributes. Image construction is probably best regarded as an inductive reasoning operation since it involves constructing a general rule from particular stimuli. Response evaluation, on the other hand, involves deductive reasoning, since it depends on the evaluation of specifics according to a general rule.

In cognitive process outcome analyses, subjects might be given a verbal analogy item such as:

STEM tree : sap :: man :

ALTERNATIVES
1. axe
2. woman
3. maple
4. blood
5. arm

For the image construction subtask the subject is asked to specify the rule or set of attributes for the ideal completion of the analogy item. For the response evaluation subtask, the subject is given an analogy 'image' and asked to select the response alternative that best fulfills the image. Verbal classification subtasks might be constructed in the same way as the analogy subtasks for the various cognitive ability components. Whitely's data support the feasibility of modeling response accuracy on verbal aptitude items from image construction and response evaluation operations. The inclusion of these subtasks account for from 70 to 83 percent of the variance in item performance.

THE CHRONOMETRIC ANALYSIS APPROACH TO THE EXAMINATION OF TEST ITEM PERFORMANCE

Frederiksen (1980) and his colleagues have sought to develop a series of cognitive ability component measures that are representative of the verbal information processing components involved in reading text. Their measures are designed to assess skills involved in the translation of letter patterns into sound patterns, in the recognition and encoding of patterns, in the retrieval of semantic information, and in the formulation of representations of text. The theoretical model that guides the selection of cognitive ability component measures for Frederiksen and his colleagues is defined by four levels of verbal information processing: (1) visual feature extraction, (2) perceptual encoding, (3) decoding and (4) lexical analysis. Visual feature extraction is the operation by which different types of information about the stimulus display are extracted. Perceptual encoding is the operation by which information is input into the system, and decoding is the operation by which arbitrary physical patterns are recognized as representations of grapheme and phoneme concepts in the lexicon.

In lexical analysis an attempt is made to match letter strings input in the preceding stages to appropriate semantic referents. For phrase and sentence units, analysis is also directed at organizing these meaning elements into coherent text representations. Lexical, semantic, and syntactic knowledge is called upon in the identification of lexical items and in phrase and sentential analysis. The lexical analysis process may be either data driven or hypothesis driven. When lexical analysis is data driven, grapheme and phoneme data alone drive the analysis process. When lexical analysis is hypothesis driven, information available from the analysis of previous text supplements the data driven analysis process. Contextual information is encoded by the reader and serves to generate hypotheses about subsequent text. The reader may engage in an iterative process of discourse representation and revision.

Frederiksen and his colleagues propose that skilled readers are better able to execute cognitive processing operations, gain access to and search memory stores, and define processing strategies at all levels. An advantage in visual feature extraction, perceptual encoding, decoding and data driven lexical access is hypothesized for skilled readers. It is hypothesized that skilled readers are better able to integrate information from perceptual and contextual sources in generating hypotheses about text and in gaining access to memory stores.

The chronometric analysis approach to the assessment of cognitive processing operations, stores, and strategies holds that the monitoring or processing time provides an important tool for the measurement of cognitive ability components. Chronometric analysis looks at reaction time differences for experimental conditions that vary the processing load placed on a single cognitive ability subsystem. The reaction time contrasts provide a measure of relative processing difficulty under the contrasted conditions.

Frederiksen and his coworkers have examined verbal performance using such tasks as the 'pseudoword decoding' task and the 'reading in context' task. In Frederiksen's pseudoword decoding task, subjects are asked to pronounce letter strings bearing a close resemblance to English forms. The letter strings represent a number of different variations, including variations in length, number of syllables, and type of vowel. The subject's reaction time from the presentation of the display to the onset of vocalization is the dependent variable. Increases in reaction time have been observed for each added letter in a letter string, for each added syllable, and for letter strings containing digraph rather than single vowels. The reaction time differences are assumed to be indicative of the additional processing time required to handle the more complex letter string forms.

The reading in context task centers on the use a subject makes of prior context in generating perceptual hypotheses in reading. The task presents the subject with a series of displays in three frames. The first frame contains an incomplete paragraph. The second frame is blank, and the third frame presents the final phrase of the passage. Subjects are presented with the context paragraph, they are instructed to read it at their own pace and press a response button when they have finished. The blank frame is then presented for 200 msc. The final passage phrase frame follows and is projected for 200 msc. The dependent variable is the number of words or word fragments reported correctly for the third frame. Subjects are presented with all three frames in one condition. In a second condition, subjects are presented only the second and third frames. Experimenters are able to assess the subject's use of context in generating and testing hypothesized word sequences by looking at visual span measurements, defined as the number of letter spaces from the leftmost correct reported letter to the rightmost correct letter. Increases in visual span have been observed for the condition where frame one provides prior context. The increase in visual span is assumed to be indicative of the use of information structures provided by prior context to construct hypotheses about subsequent text.

THE KINTSCH AND VAN DIJK PROSE PROCESSING APPROACH TO THE EXAMINATION OF VERBAL PERFORMANCE

The Kintsch and van Dijk (1978) prose processing model attempts to describe the system of mental operations that underlie text comprehension. The model is based on the premise that the comprehension act can be decomposed into component processes. The Kintsch and van Dijk prose processing model has its roots in the propositional theory outlined by Kintsch in The Representation of Meaning in Memory (1974). The scheme is further explained by Turner and Greene (1978); these authors also provide a step-by-step guide to propositionalizing text.

The Kintsch and van Dijk prose processing model is concerned primarily with semantic structures. A full grammar, necessary for both the interpretation and production of text, is not specified. The model operates at the level of assumed underlying semantic structures. The theory posits that comprehension involves knowledge use and inference construction. The model does not, however, specify the knowledge bases necessary for comprehension, nor does it disucss the process involved in inference construction.

The Kintsch and van Dijk prose processing model represents textual information in terms of a text base. A text base is an ordered set of interrelated propositions depicting the underlying meaning of prose. Propositions are idea units; each proposition represents a single idea. A proposition consists of a relation (previously called a predicate) and one or more arguments. The relation connects sets of arguments to form an idea unit. The arguments are either concepts or propositions themselves. A concept is realized in language by a word or phrase. The words themselves are inconsequential. It is the abstract concepts they represent that are of interest. Kintsch and van Dijk have adopted the convention of writing a proposition as follows:

(TRACK, ROCKET, RADAR)

The relation is TRACK. The first argument is ROCKET which functions in the semantic role of an object; and the second argument is RADAR which serves the semantic role of instrument of the action defined by the relation. The actual English text for this proposition might be expressed as : "The radar tracked the rocket", or "The rocket was tracked by radar".

Propositions can be classified into three classes: Prediction, Modification, and Connection. These classes are defined by the types of relations propositions contain. Relation types impose constraints on the classes of arguments that can be taken.

Predicate propositions express ideas of action or being. The relations are usually verbs. Arguments serve such semantic roles as agent, experiencer, instrument, object, source, or goal of the stated action. Nominal propositions, expressing set membership, and references may also be predicate propositions. A referential proposition is one which states that the referent of one argument is the same as that of a second argument. Propositions of reference are frequently implied.

Modifier propositions change a concept by restricting or limiting it by means of another concept. Four different types of modifiers are discussed: Qualifiers, Quantifiers, Partitives and Negations. These classes indicate the specific type of modification that is involved. Qualifier propositions limit or restrict the scope of an argument or proposition by expressing a quality or attribute of it. Quantifier propositions express definite or indefinite quantities. Partitive propositions indicate a part of a collective whole. Propositions of negation express the complement of a proposition.

Connective propositions relate text facts or propositions to each other. Connective propositions may be expressed in the text or they may be inferred. They are important to providing text cohesion. The arguments of connective propositions are often propositions themselves. Eight categories of connectives are specified.

1. Conjunction, expressing union, association, or combination.
2. Disjunction, expressing opposition or alternatives.
3. Causality, expressing cause-and-effect or correlated events.
4. Purpose, expressing reason, purpose or intent.
5. Concession, expressing admission of a point or yielding.
6. Contrast, expressing divergence or comparison.
7. Condition, expressing prerequisite states, restriction, or qualification.
8. Circumstance, expressing time, location or mode of action.

A text base, then, is a cohesive, interrelated set of predicate, modifier, and connective propositions. These propositions represent the meaning of text. The target text may be coherent, connected discourse united by a common theme or topic or it may be incomplete and characterized by missing logical links, facts, references, etc. The propositions suggested by the text itself may not be sufficient to form a connected and coherent text base. The reader may be called upon to supply prerequisite general or contextual knowledge or to make inferences about possible, likely or necessary bridging propositions in order to establish semantic coherence. The incidence of inference construction is recognized by the Kintsch and van Dijk prose processing model; the model does not address itself to the nature of processing inherent in inference construction.

Turner and Greene (1978) state that the Kintsch and van Dijk model of prose processing can be used as a tool for research into the cognitive processes involved in the comprehension of text. Kintsch and van Dijk have examined the relationship between meaning as represented using propositional analysis and behavioral indices of processing difficulty.

They have demonstrated a relation between number of propositions expressed in a text base and processing difficulty. Kintsch and Keenan (1973) systematically varied the number of propositions in a text base while holding constant the number of words in the selection. They observed that reading time increased and recall decreased as a function of number of propositions expressed. Kintsch, Kozminsky, Streby, McKoon, & Keenan (1975) looked at processing difficulty as a function of the number of different arguments used in a text base. Short texts controlled for number of words and propositions and differing in number of different arguments were read and recalled by groups of subjects. Reading times were longer and recall poorer for texts with many different arguments. Texts with fewer arguments had shorter reading times and higher levels of recall. Kintsch and van Dijk conclude that comprehension difficulty is positively related to the number of propositions that must be processed and the number of different arguments that need be encoded.

Miller and Kintsch (1980) propose that, in addition to propositional density and number of different arguments, comprehension difficulty is related to the incidence of inference construction. Using a computer program written in two parts, a chunking program to perform the initial segmentation of text and a coherence program to simulate processes involved in maintaining semantic coherence, Miller and Kintsch examined processing difficulty and inference construction. Miller and Kinstch modeled twenty texts of varying readability and used these data to predict empirically generated recall and readability statistics. They found significant relations between number of connecting or bridging inferences necessary to connect segments of text and reading time and recall data. They summarize that the processing necessary to generate inferences implied by or implying stated propositions and necessary to semantic coherence is psychologically relevant and related to comprehension difficulty.

A MODEL OF VERBAL PERFORMANCE

The theory and methods of factor analytic, information processing, chronometric analysis, cognitive correlates and componential analysis approaches to the study of individual differences are summarized above. This review of the definition and measurement of cognitive processing operations, stores, and strategies involved in performance on verbal tasks provides a framework for the following general model of verbal performance.

The model of verbal performance outlined in Figure 1 brings together portions of the paradigms outlined by Frederiksen, Hunt, Carroll, Pellegrino, Kintsch, and others. The model describes verbal performance in terms of the subset of processing skills associated with text analysis.

The model depicts verbal performance by five processing or storage structures. The first structure might be thought of as a perceptual processor, the second as an executive or control processor, the third as the locus of lexical access and semantic-syntactic analysis, the fourth as knowledge-based information and mechanistic information-free storage, and the fifth as a response processor. Each structure is discussed below. The structures are not strictly serially or hierarchically ordered. The flow of information within the system is not necessarily sequential or parallel. A schematic of the model follows.

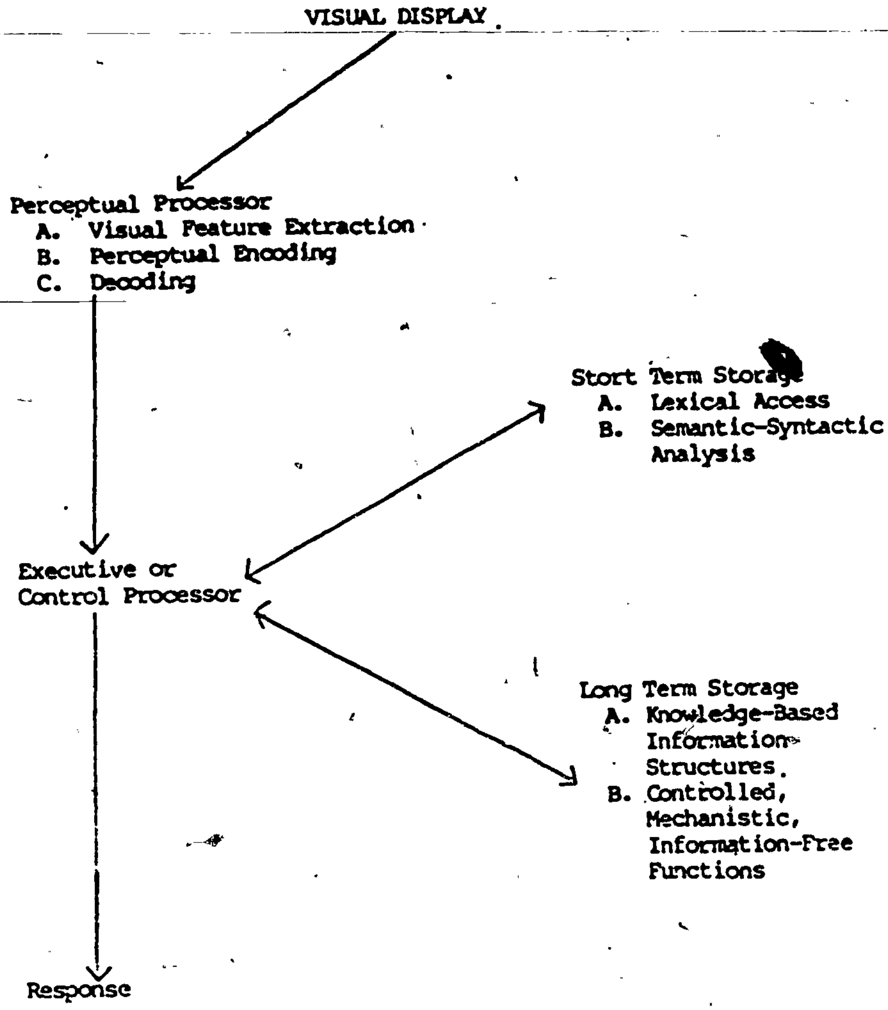

Figure 1. Model of verbal performance.

The PERCEPTUAL PROCESSOR is the structure that inputs stimulus information to the processing system. It includes the set of operations that converts the physical stimulus to a form that is appropriate for the task; it includes the operations that match stimuli to appropriate grapheme and phoneme representations. The perceptual processor is characterized by three operations described by Frederiksen as: visual feature extraction, perceptual encoding, and decoding. Visual feature extraction is the operation by which different types of information about the stimulus display are extracted. Perceptual encoding is the operation by which information is input into the system, and decoding is the operation by which arbitrary physical patterns are recognized as representations of grapheme and phoneme concepts in the lexicon. These operations may be thought of as automated, mechanistic processes for the samples of examinees considered here. The processor may be thought of as a short term sensory storage or buffer component.

The EXECUTIVE OR CONTROL PROCESSOR is the structure that controls the flow of information in the system and has access to the various levels of memory storage. This structure determines the nature of a problem, selects processes for solving a problem, decides on a strategy for combining these processes, decides how to allocate processing resources, decides how to represent the information upon which processes act, and monitors solution processes. This structure is analogous to Sternberg's metacomponent and to the executive processor described by Snow, Whitely, and others.

The LEXICAL ACCESS/SEMANTIC-SYNTACTIC ANALYSIS STRUCTURE is a short term storage or working memory structure. In lexical access/semantic-syntactic analysis, an attempt is made to match letter strings input at the perceptual processing stage to appropriate semantic referents. Analysis is directed at attaching meaning to perceptual patterns. For phrase and sentence units, analysis is also directed at organizing these meaning elements into coherent text representations. Lexical, semantic, and syntactic knowledge is called upon in the identification of words and in phrase and sentential analysis.

Lexical Access is defined as the retrieval of information about individual words from long term memory. In lexical access, grapheme and phoneme data drive the retrieval of semantic information.

Semantic-syntactic analysis takes place in short term memory; it is defined by the retrieval of knowledge-based structures and information-free functions. These structures are discussed by Hunt (1978). In semantic-syntactic analysis, the knowledge-based and information-free long term memory structures are accessed and, in the case of the information-free functions, executed in short term memory to form a semantically coherent representation of prose. Information about individual words stored in long term memory is retrieved and arranged to form a semantically coherent structure. Kintsch and van Dijk (1978) have developed a prose processing model which references the types of knowledge-based structures and information-free functions involved in semantic-syntactic analysis.

The fourth structure is a long term storage structure. This structure is the locus of KNOWLEDGE-BASED INFORMATION STRUCTURES and CONTROLLED, MECHANISTIC INFORMATION-FREE FUNCTIONS. The knowledge-based information structures represent semantic and syntactic knowledge. These structures represent the ability to deal with words and the concepts they represent. They reflect experience with and cognizance of the English language. The knowledge-based information structures are also associated with knowledge of the world and world events. These knowledge structures are mediated by verbal knowledge but represent information about the world ancillary to mastery of the English language.

The controlled, mechanistic, information-free functions are the operations by which information structures are transformed to equivalent structures necessary for task performance. No semantic or syntactic information is associated with these strategic knowledge structures. These operators are defined by learned, stored transformation rules. Examples of controlled, mechanistic information-free operators are the processes of comparing and inferring. These operators perform such functions as judging the equivalence of two information structures or generating missing bridging information to establish semantic coherence for a text.

The comparison operator, for example, is the structure by which two or more information structures are examined and judged to be the same or different. The inferencing operator is a structure used to establish links between propositions when semantic coherence for a text is not maintained via shared arguments.

Inferencing strategies generate the missing or non-derivable connecting or bridging information necessary to maintain semantic coherence. Inference processes may be used to determine reference or define enabling conditions. They may also be used to specify resultant events, that is, events not entailed by stated conditions, but bearing a high probability of occurrence given stated conditions.

The final structure is the RESPONSE OPERATOR. This is the structure through which appropriate motor actions are selected and executed. The response operator is the structure by which the examinee makes an observable response, such as selecting one response from a set of multiple alternatives.

The verbal comprehension or verbal information processing model characterizes performance with respect to the subset of processes which underlie text comprehension. The model synthesizes portions of processing paradigms described by Frederiksen, Hunt, Carroll, Pellegrino, Kintsch, and others. It provides a useful conceptual framework for the examination of cognitive processing operations, stores, and strategies involved in performance on verbal tasks.

REFERENCES

Barnes, G. M., & Whitely, S. E. (in preparation). Problem restructuring processes for ill structured verbal analogies. Memory and Cognition.

Burt, C. (1970). The genetics of intelligence. In W. B. Dockrell (Ed.), On intelligence. Toronto: The Ontario Institute for Studies in Education.

Carroll, J. B. (1976). Psychometric tests as cognitive tests: A new structure of intellect. In L. B. Resnick (Ed.), The nature of intelligence. Hillsdale, NJ: Lawrence Erlbaum Associates.

Cooper, L. A. (1980). Spatial information processing: Strategies for research, In R. E. Snow, P. A. Federico, & W. E. Montague (Eds.), Aptitude, learning and instruction, Vol. 1. Hillsdale, NJ: Lawrence Erlbaum Associates.

Egan, D. E. (1979). Testing based on understanding: Implications from studies of spatial ability. Intelligence, 3, 1-15.

Ekstrom, R. B., French, J. W., & Harman, H. H. (1976). Manual for kit of factor referenced cognitive tests. Princeton, NJ: Educational Testing Service.

Falmagne, R. J. (Ed.). (1975). Reasoning: Representation and process. Hillsdale, NJ: Lawrence Erlbaum Associates.

Frederiksen, J. A. (1978). Chronometric study of component skills in reading. Cambridge, MA: Bolt, Beranek and Newman.

Frederiksen, J. A. (1980). Component skills in reading: Measurement of individual differences through chronometric analysis. In R. E. Snow, P. A. Federico, & W. E. Montague (Eds.), Aptitude, learning and instruction, Vol. 1. Hillsdale, NJ: Lawrence Erlbaum Associates.

Gentile, J. R., Tedesco-Stratton, L., Davis, E., Lund, N. J., & Agunane, B. C. (1977). Associative responding versus analogical reasoning by children. Intelligence, 1, 369-380.

Guilford, J. P. (1967). The nature of human intelligence. New York: McGraw Hill.

Hunt, E. (1971). What kind of computer is man? Cognitive Psychology, 2, 57-98.

Hunt, E. (1973). The memory we must have. In R. Schank & K. Colby (Eds.), Computer models of thought and language. San Francisco: Freeman.

Hunt, E. (1974). Quote the raven? Nevermore! In L. Gregg (Ed.), Knowledge and cognition. Hillsdale, NJ: Lawrence Erlbaum Associates.

Hunt, E. (1976). Varieties of cognitive power. In L. B. Resnik (Ed.), The nature of intelligence. Hillsdale, NJ: Lawrence Erlbaum Associates.

Hunt, E. (1978). Mechanics of verbal ability. Psychological Review, 85, 109-130.

Hunt, E. (1980). Intelligence as an information-processing concept. British Journal of Psychology, 71, 449-474.

Hunt, E., Frost, N., & Lunneborg, D. (1973). Individual differences in cognition: A new approach to intelligence. In G. H. Bower (Ed.), The psychology of learning and motivation, Vol. 7. New York: Academic Press.

Hunt, E., & Lansman, M. (1975). Cognitive theory applied to individual differences. In W. K. Estes (Ed.), Handbook of learning and cognitive processes: Introduction to concepts and issues, Vol. 1. Hillsdale, NJ: Lawrence Erlbaum Associates.

Hunt, E., Lunneborg, C., & Lewis, J. (1975). What does it mean to be high verbal? Cognitive Psychology, 7, 194-222.

Kintsch, W. (1974). The representation of meaning in memory. Hillsdale, NJ: Lawrence Erlbaum Associates.

Kintsch, W., & Keenan, J. (1973). Reading rate and retention as a function of the number of propositions in the base structure of sentences. Cognitive Psychology, 5, 257-274.

Kintsch, W., Kozminsky, E., Streby, W. J., McKoon, G., & Keenan, J. M. (1975). Comprehension and recall of text as a function of content variables. Journal of Verbal Learning and Verbal Behavior, 14, 196-214.

Kintsch, W., & van Dijk, T. (1978). Toward a model of text comprehension and production. Psychology Review, 85, 363-394.

Miller, J. R., & Kintsch, W. (1980). Readability and recall of short prose passages: A theoretical analysis. Journal of Experimental Psychology: Human Learning and Memory, 6, 335-354.

Mulholland, T., Pellegrino, J. W., & Glaser, R. (1980). Components of geometric analogy solution. Cognitive Psychology, 12, 252-284.

Neisser, U. (1967). Cognitive psychology. New York: Appleton-Century-Crofts.

Newell, A., & Simon, H. A. (1972). Human problem solving. Englewood Cliffs, NJ: Prentice-Hall.

Pellegrino, J. W., & Glaser, R. (1979). Cognitive correlates and components in the analysis of individual differences. Intelligence, 3, 187-214.

Pellegrino, J. W., & Glaser, R. (1980). Components of inductive reasoning. In R. E. Snow, P. A. Federico, & W. E. Montague (Eds.), Aptitude, learning and instruction, Vol. 1. Hillsdale, NJ: Lawrence Erlbaum Associates.

Posner, M. I. (1969). Abstraction and the process of recognition. In G. H. Bower & T. J. Spence (Eds.), The psychology of learning and motivation: Advances in research and theory. New York: Academic Press.

Posner, M. I., & Mitchell, R. F. (1967). Chronometric analysis of classification. Psychological Review, 74, 392-409.

Rose, A. M. (1980). Information-processing abilities. In R. E. Snow, P. A. Federico, & W. E. Montague (Eds.), Aptitude, learning and instruction, Vol. 1. Hillsdale, NJ: Lawrence Erlbaum Associates.

Royer, F. L. (1977). Information processing in the block design task. Intelligence, 1, 32-50.

Simon, H. A. (1976). Identifying basic abilities underlying intelligent performance of complex tasks. In L. B. Resnik (Ed.), The nature of intelligence. Hillsdale, NJ: Lawrence Erlbaum Associates.

Sternberg, R. J. (1977a). Component processes in analogical reasoning. Psychological Review, 31, 356-378.

Sternberg, R. J. (1977b). Intelligence, information processing and analogical reasoning: The componential analysis of human abilities. Hillsdale, NJ: Lawrence Erlbaum Associates.

Sternberg, R. J. (1980). Toward a unified componential theory of human reasoning. In M. Friedman, J. Das, & N. O'Connor (Eds.), Intelligence and learning. New York: Plenum Press.

Sternberg, R. J., Guyote, M. J., & Turner, M. E. (1980). Deductive reasoning. In R. E. Snow, P. A. Federico, & W. E. Montague (Eds.), Aptitude, learning and instruction, Vol. 1. Hillsdale, NJ: Lawrence Erlbaum Associates.

Sternberg, R. J., & Weil, E. M. (1980). An aptitude-strategy interaction in linear syllogistic reasoning. Journal of Educational Psychology, 72, 226-234.

Thurstone, L. L. (1947). Multiple factor analysis. Chicago, IL: University of Chicago Press.

Turner, A., & Greene, E. (1978). Construction and use of a propositional text base. JSAS Catalogue of Selected Documents in Psychology, 3, 58, MS #1713.

Whitely, S. E. (1980). Maximum likelihood estimation of multicomponent latent trait models for independent processes (Technical Report, NIE-80-3). Washington, DC: National Institute of Education.

Whitely, S. E. (1981). Measuring aptitude processes with multicomponent latent trait models. Journal of Educational Measurement, 18, 67-84.

Whitely, S. E., & Barnes, G. M. (1979). The implications of processing event sequences for theories of analogical reasoning. Memory and Cognition, 1, 323-331.

Whitely, S. E., & Schneider, L. M. (1980). Process outcome models for verbal aptitude (Technical Report, NIE-80-1). Washington, DC: National Institute of Education.

Whitely, S. E., & Schneider, L. M. (1981). Information structure for geometric analogies: A test theory approach. Applied Psychological Measurement, 5, 383-397.